JEM

Hurricane effects, mitigation, and preparedness in the Caribbean: Perspectives on high importance–low prevalence practices from agricultural advisors

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ABSTRACT

Frequent hurricanes affect agricultural productivity, food security, economic security, and human wellbeing in the Caribbean islands. We assessed recent hurricane effects on the agricultural sector, and the challenges faced by farmers, foresters, and advisors related to hurricane preparedness and recovery in Puerto Rico and US Virgin Islands (USVI). We used qualitative and quantitative survey methods to compile perspectives from agricultural advisors related to hurricane effects on farmlands, preparedness and recovery measures taken by land managers, and the needs regarding preparing for and responding to future hurricanes. Survey responses from over 200 advisors at eight institutions provided insight into the most devastating hurricane effects across farmlands, including issues related to power outages, communication, road access, and fallen trees. Our results highlight strategies considered critical for hurricane preparedness and recovery but not prevalent in application among land managers. Advisors' perceptions suggested that farmers and ranchers apply essential recovery practices, but critical short-term preparedness practices are limited, and long-term preparedness practices are uncommon. Advisors also indicated the need for more training and educational resources to improve hurricane recovery response. We conclude that better planning to minimize the vulnerability to future hurricanes can be achieved through an increased understanding of how preparedness and recovery practices help mitigate hurricane effects, improved interagency coordination for hurricane response and preparedness, and integrated educational campaigns with advisors and land managers.

Key words: disasters, risks, tropical agriculture, emergency management, hurricane resilience

INTRODUCTION

Agricultural economies and food security in the Caribbean islands are vulnerable to extreme weather events due to their location in the Atlantic Hurricane Belt, geographic isolation from continental-based resources, limited geographic and economic scale, and dependence on imported goods. The Caribbean basin is exposed to an average of six hurricanes per year,[1] and the Eastern Caribbean is ranked as one of the world's most disaster-prone regions due to its high incidence of hurricanes.[2] Furthermore, climate models predict increases in hurricane intensity in the region with rising global temperatures. Although models indicate that the total number of hurricanes will remain similar to past patterns, significant increases in the severity of hurricanes and associated rainfall are projected for the Caribbean basin.[3] An important mechanism to reduce vulnerability is to learn from past experiences and incorporate those lessons into planning, preparation, and supporting mitigation actions at different scales.

Recurrent hurricanes have shaped Caribbean social and ecological landscapes. Repeated damages

DOI:10.5055/jem.0585

to crops, livestock, forests, and infrastructure have led to losses in the immediate aftermath of a hurricane, with persistent effects in some sectors.[4,5] The severity of short- and long-term effects of hurricanes is related to vulnerabilities to the effects of high winds and heavy rains,[6] and also to constraints in executing effective planning, response, and recovery intended to reduce the secondary effects of hurricanes. Secondary effects include extended losses of power, transportation infrastructure, energy, food distribution infrastructure, and emergency medical support.[5] Social and economic factors associated with hurricane vulnerability in the agriculture and forestry sectors in Puerto Rico and the US Virgin Islands (USVI) include high dependence on government services and public goods such as electricity, water, and transportation. Reducing risk therefore requires an understanding of vulnerabilities to primary and secondary effects of hurricanes that can be addressed in the planning, response, and recovery phases.

The 2017 hurricane season represented extraordinary challenges for the US Caribbean. Puerto Rico and USVI were hit by hurricane Irma (Category 5 on the Saffir-Simpson Hurricane Wind Scale (SSWS)) on September 6 and hurricane María (Category 5 SSWS for USVI and Category 4 SSWS for Puerto Rico) on September 20. The social, ecological, and economic impacts were unprecedented in recent history. Economic losses surpassed $43 billion in Puerto Rico and $7.5 billion in USVI.[7,8] In Puerto Rico, losses in agricultural production and agricultural infrastructure surpassed $2 billion.[3] No official estimates of losses in USVI agricultural production were reported, although damages were similar in scope to those of Puerto Rico.[3] The lack of agricultural production and ability to bring products to markets following hurricanes Irma and María, combined with restrictions on food imports and logistical challenges at ports and distribution centers, exacerbated food insecurity across the islands.[9]

Despite the enormous impact of hurricanes on agriculture and forestry in the US Caribbean, there has been relatively limited development of quantitative or qualitative information on the prevalence and value of mitigation and adaptation strategies that alleviate the effects of hurricanes on agricultural systems in the region. Exceptions include studies on farmers' experiences and challenges after hurricane María in Puerto Rico by Rodriguez and Niles,[10] the response of coffee farmers to Hurricane María in Puerto Rico by Perfecto et al.,[11] and on the opportunities and challenges for hurricane resilience on agricultural and forest land in the US Southeast and Caribbean by Wiener et al.[12] Each of these studies demonstrate the importance of systematically learning from extreme climate events in order to better inform mitigation and adaptation practices and policies.

Agricultural advisors represent a group of professionals who, given their direct connection with landowners, act as an information intermediary between the scientific, public-policy, and user communities.[12,13] Observations provided by agricultural advisors serve as a reflection of the landowners' perception of climate challenges, and their testimonies are deemed relevant to facilitate means for climate adaptation.[14,15] A major strength of advisors comes from their on-the-ground relationships with the farmers they serve and a close-knit understanding of social contexts. Additionally, advisors are part of the agencies they work for and bring with them the capacity and limitations of their agencies in terms of hurricane preparation, response, and recovery. Agricultural advisors, however, also may be affected personally by the particular challenges that hurricanes bring, which can make it difficult for them to serve their clients in the immediate aftermath of a hurricane or other disaster. Understanding these challenges is a first step toward supporting agricultural advisors as they participate in hurricane recovery, and better prepare for hurricane events.

In this study, we analyze the challenges posed by hurricanes Irma and María on the US Caribbean agriculture sector through a systematic assessment of the experiences and perceptions of agricultural advisors in this region. We surveyed agricultural advisors of eight public boundary organizations in Puerto Rico and USVI to gather information on their perceptions of hurricane effects on the sectors they serve, the relative importance of existing strategies for hurricane preparedness and recovery, and the adoption of these

strategies by farmers. Moreover, this research evaluates the prevalence or gaps in the implementation of critical practices to mitigate hurricane effects on farmlands.

Background

Physical setting and agriculture. The US Caribbean includes six large islands making up Puerto Rico and USVI, and over 800 mostly uninhabited smaller islands and cays. The two archipelagos cover 9,450 km^2 with a population of 3.4 million in Puerto Rico and 104,000 in USVI. Steep gradients in rainfall and high diversity of soils allow for a great variety of agricultural products. Hay and pasture cover the greatest area, dairy generates the most economic activity, and aside from grasslands, coffee represents the largest total area of agricultural land (5,221 ha). Other principal crops include plantains, bananas, other fruits and vegetables, hay for livestock, ornamentals and nurseries, and root crops for local consumption.[16] Agriculture contributes to about 1 percent of the GDP in Puerto Rico[17] and about 2 percent in USVI.[18] Agriculture is important to local livelihoods and represents a prevalent land use across the territories. Puerto Rico contains a total of 191,695 ha of farmlands from 8,230 farms, with farms being an average of 23 ha, while USVI contains approximately a total of 2,380 ha of farmlands, from 219 farms, with farms being an average of 11 ha.[16] Approximately, 22 percent of Puerto Rico's and 7 percent of USVI's land areas are occupied by farms (croplands, pastures, and grazing lands).[16] New initiatives by governments, NGOs, private operations, and farmers organizations aim to expand the agrarian sector by developing new products, markets, and improving supply chains.[19]

Hurricane effects on agriculture in the US Caribbean. The US Caribbean is exposed to tropical cyclones, ie, hurricanes, storms, and depressions, between June and November (hurricane season). From 1867 to 2017, 94 storms and hurricanes passed over the US Caribbean.[20] From 1950 to 2018, 32 hurricanes passed within 322 km (~200 miles) of the main islands, including six hurricanes passing directly over Puerto Rico and 11 hurricanes passing directly over or 80 km (50 miles) from the islands of St. Croix, St. Thomas, or St. John.[21] Hurricanes have been responsible for major economic losses to the agricultural sector of the US Caribbean (Table 1). For example, Hurricane Georges (Category 3 SSWS) in 1998 caused a loss of $308 million to the agricultural sector of Puerto Rico ($665.6 in 2020),[22] representing 7 percent of the total economic losses to the commonwealth.[23] Losses were mostly in coffee ($97.7 million), plantains

Table 1. Economic losses in the agricultural sector in a sample of hurricanes that affected Puerto Rico (USD $, not adjusted for inflation). Data obtained from the Puerto Rico Planning Board and the Puerto Rico Department of Agriculture[7,29,30]

Hurricane name (Category Saffir Simpson Hurricane Wind Scale)	Date	Estimated economic losses (gross, USD, not adjusted)	Economic losses in the agricultural sector (USD, not adjusted)	Percentage of total	Percentage of losses in agricultural products	Percentage of losses in agricultural infrastructure
Luis (4)	September 4-6, 1995	147,529,045	12,015,415	8	98.7	1.4
Marilyn (2)	September 15-16, 1995	59,047,640	8,043,729	14	NA	0.9
Berta (1)	July 8, 1996	33,110,668	6,006,140	18	NA	2.2
Hortense (1)	September 9-10, 1996	489,547,129	128,390,000	26	94.7	5.3
Georges (3)	September 21, 1998	4,287,000,000	307,900,000	7	NA	25.0
Irma (5)	September 6, 2017	1,656,900,000	45,820,907	3	98.7	1.3
María (4)	September 20, 2017	40,661,600,000	2,011,365,815	5	9.3	90.7

($42.8 m), and bananas ($7.7 m). The coffee sector lost 64 percent of its crops causing the abandonment of coffee production by some farmers and a decrease in coffee farms in the following years.[24] Furthermore, Borkhataria et al.[24] report that hurricanes were considered by farmers to be the most important obstacle to coffee production in Puerto Rico followed by lack of capital, unavailability of workers, and erosion, among others.

Hurricanes Irma and María effects on agriculture, forests, and infrastructure. Hurricanes Irma and María (2017) caused catastrophic damages to crops and infrastructure across farmlands in Puerto Rico and USVI. Their combined effects likely constitute the greatest effect to the agricultural economy in recent years (Table 1). In Puerto Rico, crop insurance indemnities paid to farmers to mitigate crop losses arising from hurricanes Irma and María in 2017 encompassed 94 percent of the total indemnities paid in Puerto Rico in the 2010-2019 period (~34 million).[25] Losses in crops, ornamentals, livestock, and animal products surpassed $2 billion. In USVI, farms, ranches, and infrastructure including government agricultural offices experienced sizable damages; however, no official estimates of the economic losses caused by the storms have been published to date. Both Puerto Rico and USVI experienced widespread defoliation, branch loss, and mortality of trees by hurricane winds.[6,26] Millions of downed trees affected infrastructure, power lines, roads, and trails, filling right-of-ways with vegetated debris. Vegetative debris management became a costly and challenging issue due to prohibitions on burning, limited landfill capacity, and public concern about lack of appropriate use of wood resources. Potentially valuable downed trees were not utilized as wood products due to the lack of planning, an underdeveloped market for salvage logs, and a poorly coordinated system to utilize salvage logs.

Hurricanes Irma and María also caused the failure of critical electric infrastructure and the loss of power throughout the region, including severe damage to telecommunications infrastructure.[3] In Puerto Rico, approximately 80 percent of all cell phone towers were still out of service, and television and internet communications were cut off throughout the island a month after these hurricanes struck.[27,28] Radio became the only means to reach the public and transmit information about relief efforts, as well as the principal means of communication between agencies and citizens.[28] Landslides, fallen debris, damaged roads and bridges, electrical posts and trees downed by winds, and overflowing rivers caused widespread disruption in transportation in the aftermath of the 2017 hurricanes. Particularly in rural areas, many roads were blocked or otherwise could not be used for an extended period exceeding 6 months in some places, hindering the distribution of relief resources (food, medicines, and tarps), and delaying the restoration of utilities, eg, power lines.[27] In light of these challenges, and the potential for climate change to exacerbate many of those challenges, research on the prevalence and effectiveness of hurricane-related strategies for preparation, adaptation, and recovery is important to continued economic and food security in the region.

METHODS

We developed and administered a survey instrument to better understand the perspectives of public sector land management advisors regarding hurricane preparedness and recovery in Puerto Rico and USVI. The survey was initially created for advisors working for the Natural Resources Conservation Service (NRCS), Cooperative Extension, and state forestry agencies in 2017, as part of a regional analysis of hurricane effects across nine states in the Southeast US, Puerto Rico, and USVI.[12] In 2018, we expanded the survey to include advisors working in selected agencies that provide agricultural support and are involved in hurricane preparedness and recovery in Puerto Rico and USVI (Table 2). The survey was pretested by six agricultural advisors from NRCS, Cooperative Extension, and the Puerto Rico Department of Agriculture (PRDA) and modified to improve clarity based on their input. The survey was available in English and Spanish. Translation to Spanish was conducted by an accredited translator and confirmed by two native Spanish speakers from the US Forest Service.

Table 2. Description of organizations in PR and USVI providing assistance to the agricultural sector after hurricanes that participated in this study		
Institution	**Description**	**Role in hurricane assistance**
Cooperative Extension: University of Puerto Rico-Mayagüez and University of the Virgin Islands	Cooperative Extension System (CES) is hosted by Land Grant Universities. Extensionists provide technical assistance, and training incorporating the latest scientific research on agriculture, natural resources, health, nutrition, and more	Provides resources and training related to disaster preparedness and recovery
Puerto Rico Department of Agriculture (DAPR)	DAPR facilitates and promotes agricultural production, commercial fishing, and aquaculture in Puerto Rico; administers rural development, credit, and conservation programs designed to implement national growth policies; conducts scientific and technological research in all areas of agriculture	First responders. Hurricane damage evaluations. Provision of information on recovery aids and programs. Coordination of animal care and mortality management (livestock and poultry). Support in debris removal
Natural Resources Conservation Service (NRCS)—Caribbean Area (PR and USVI)	Provides conservation planning and technical assistance to land managers. Designs and promotes land management conservation practices and programs	Assist farmers with the implementation of agricultural conservation practices that address hurricane-related concerns. Provides technical and financial assistance after disasters to reduce threats to life and property through easements and recovery activities
Farm Insurance Corporation of Puerto Rico	Administers and distributes government-subsidized agricultural insurance to farmers against losses or damages caused to plantations and crops by natural risks such as hurricanes, floods, and named storms	Assist farmers in acquiring farm insurance. Evaluate farm damages after hurricane events and process crop insurance compensation
APHIS—Veterinary Services	Protects and promotes agricultural health, regulating genetically engineered organisms, administering the Animal Welfare Act and carrying out wildlife damage management activities	Provide support during emergencies through the FEMA Emergency Support Function (ESF) #11, including responses to animal and agricultural health issues; provision of technical expertise, coordination and support of animal and agricultural emergency management
Land Authority of Puerto Rico	The Land Authority is a programmatic and operational component of the DAPR. Its goal is to acquire, conserve and preserve land of high agricultural value, and to facilitate the use of this land for agriculture production through land leases or sales	First emergency responders after hurricanes. Work in debris removal, farm access, flood control, and recovery assistance
Soil and Water Conservation District	Conservation districts are units of government established under state law to develop locally driven solutions to natural resources concerns. Districts work with landowners and operators to manage and protect land and water resources on private and public lands	Assist in natural resource management—eg, erosion and sediment control, stormwater management, flood control, and water use efficiency—respond to natural disasters with clean-up efforts and restoration—eg, cropland and drainage system cleanup, repair of conservation best management practices, livestock mortality issues, and waste management systems
USVI Department of Agriculture	The Virgin Islands Department of Agriculture develops, supports, and promotes an economically lucrative agricultural industry in USVI while protecting farmers, consumers, and the environment	First responders. Hurricane damage evaluations. Provision of information on preparedness strategies to reduce losses, recovery aids and programs. Coordination of animal care and mortality management (livestock and poultry)
This table describes the main public institutions that provide direct assistance to farmers, and is not meant to be comprehensive, as other agencies that deal with disaster preparedness and management might also provide direct or indirect services to farmers—eg, PR Department of Natural and Environmental Resources, PR Emergency Management Bureau, and Virgin Islands Territorial Emergency Management Agency.		

The instability in the electrical and communication services lasted beyond the hurricane events, affecting internet and phone lines in several agencies participating in this study, resulting in challenges with distributing an online survey. Thus, we adapted the online survey to a paper version and distributed these among the agencies without consistent internet access. To distribute the survey, we requested that agency directors and Deans or Associate Deans for Cooperative Extension send the survey to staff who assist farmers and who are involved in hurricane preparedness and recovery. The request for participation was sent three times between November 2018 and January 2019, following the Tailored Design Method.[31] The survey and revision to the survey (Spanish translation) were approved by the University of Florida's IRB protocol #IRB201801856 and Revision 1 for IRB Study #IRB201801856.

Survey questions focused on three main topics: (1) the main effects associated with hurricanes and associated impacts on farmers and ranchers, (2) the main challenges faced by farmers, ranchers, and advisors in dealing with hurricanes in the Caribbean, and (3) the relative importance and perceived prevalence of hurricane preparedness and recovery strategies among land managers. Question formatting included Likert scales, multiple-choice, and open-ended queries. To assess the importance of hurricane preparedness and recovery strategies, we provided a list of short-term hurricane preparedness strategies (measures taken to prepare for a forecasted hurricane arriving in less than a week), long-term hurricane preparedness strategies (measures taken to protect farms from hurricanes that may come within months or years), and hurricane recovery strategies (measures taken to assess and repair damage after a hurricane). The list of strategies was gathered from Cooperative Extension and NRCS publications and from conversations with experts. Respondents were asked to estimate the proportion of farmers and ranchers they work with who use a strategy (hereafter referred to as "prevalence"), as well as how important each strategy is for successful hurricane preparedness/recovery (hereafter referred to as "importance"). We then identified strategies with both a high-median importance and low-median prevalence and labeled them as having an importance-prevalence gap. Summary statistics of the quantitative data were calculated using SPSS statistical software.[32]

Finally, open-ended questions about the topics, (1) challenges faced by farmers and ranchers during recovery, (2) challenges faced by advisors during recovery, (3) and additional resources considered necessary by advisors to better assist farmers and ranchers with hurricane preparedness and recovery, were analyzed for themes following thematic analysis methods using Dedoose.[33,34] Responses were coded independently by two coders from the research team; mismatched codes were reviewed collectively by both coders, who came to a consensus.

RESULTS

Description of survey respondents and expert knowledge

A total of 202 agricultural advisors from eight institutions responded to the survey. The largest number of respondents were affiliated with Cooperative Extension in PR and USVI (39 percent). This was followed by advisors affiliated with PRDA (31 percent), NRCS-Caribbean Area (14 percent), and Farm Insurance Corporation (FIC) (6 percent) (Table 2). Forty-six percent of the respondents held a graduate-level degree, 37 percent a bachelor's degree, 10 percent other qualifications, eg, Associates degree and graduate courses, and 7 percent preferred not to answer. Although many of the advisors work both in Puerto Rico and USVI, 94 percent are based in Puerto Rico and only 6 percent in USVI.

The advisors surveyed reported using multiple resources and organizations for information on hurricane preparedness and recovery for professional purposes. Among a list of eight types of resources and organizations, advisors indicated that they mostly rely on information through training, workshops, and webinars (44 percent), technical reports (38 percent), resources from Cooperative Extension (35 percent), social media (31 percent), and the expertise of other colleagues (31 percent). Advisors also rely on peer-reviewed literature or journals (25 percent) and information from relief agencies or groups (22

percent), eg, the Puerto Rico Emergency Management Bureau and the Virgin Islands Territorial Emergency Management Agency. Overall, most advisors (73 percent) feel confident or very confident in their ability to assist land managers on topics related to hurricane events in general. However, confidence levels varied substantially with regard to specific hurricane-related effects. While more than 60 percent of advisors indicated that they feel confident or very confident advising on the topics of soil loss or erosion, wind damage, stormwater inundation, and landslides, advisors feel less confident advising on topics related to coastal hazards. Only 27 percent reported that they feel confident or very confident advising on coastal flooding and storm surge, and 21 percent reported the same level of confidence on saltwater intrusion topics.

Effects and challenges—agricultural lands and farmers and ranchers

Advisors ranked the perceived effects of the 2017 hurricanes on agriculture in Puerto Rico and USVI according to their level of impact on a 5-point Likert-type scale (1 = *no impact*; 2 = *low impact*; 3 = *moderate impact*; 4 = *high impact*; 5 = *devastating impact*) (Table 3). Seventy-one percent of respondents indicated that loss of power had a devastating impact, and another 23 percent indicated that loss of power as having a high impact. Fifty-eight percent indicated that loss of phone/internet communication as having a devastating impact, and another 31 percent as having a high impact. Fifty-two percent indicated impassable roads as having devastating impacts, and 37 percent as having a high impact. Likewise, 52 percent indicated fallen trees as having devastating impacts, and 32 percent as having a high impact. Sorting by mean perceived impact produced similar results. The hurricane-related effects rated as having the most devastating impact on agriculture were loss or power (μ = 4.61), loss of phone/internet communication (μ = 4.42), impassable roads (μ = 4.37), and fallen trees (μ = 4.37). Coastal flooding and storm surge flooding ranked as the effect with the lowest impact on agricultural lands in the islands (μ = 2.91) (Table 3).

Table 3. Main effects associated with hurricanes impacting farmers [scale impact: no impact (1), low impact (2), moderate impact (3), high impact (4), and devastating impact (5)]. Sorted by devastating impact

Impact	N	No impact (percent)	Low impact (percent)	Moderate impact (percent)	High impact (percent)	Devastating impact (percent)	Mean	SD
Loss of power	184	2	2	2	23	71	4.61	0.76
Loss of phone/internet communication	185	1	3	7	31	58	4.42	0.82
Impassable roads	183	1	2	8	37	52	4.37	0.79
Fallen trees	188	1	2	9	36	52	4.37	0.80
Lack of potable water	186	2	7	13	32	47	4.15	1.00
Flooding from rain	186	1	7	20	31	41	4.03	1.00
Gas shortages	184	3	4	10	42	41	4.14	0.96
Landslides	186	4	8	21	34	33	3.86	1.08
Coastal flooding/storm surge flooding	176	30	14	13	20	23	2.91	1.57
Evacuation requirements	175	10	20	33	22	15	3.13	1.19

Main challenges faced by farmers and ranchers during hurricane recovery

We analyzed the open-ended question, "In your opinion, what is the biggest challenge the farmers and ranchers you work with face during hurricane recovery?" Advisors frequently mentioned multiple challenges (Table 4). Eighty-three percent of the respondents mentioned challenges related to farm management issues, which included unavailability of farm supplies such as seeds, fertilizers, and feed for animals (mentioned by 16 percent of total respondents), unavailability of equipment and machinery (14 percent), and infrastructure damages and repair (12 percent).

In looking more specifically at farm management issues and challenges reported by respondents, several of the open-ended answers indicated the need for large equipment particularly for recovery efforts post-disaster. There was "[a] lack of heavy equipment (such as bulldozers, excavators, or diggers) needed for clearing the roads, accessing farms, preparing land to sow new crops, disposing of dead animals, and complying with health parameters." Other challenges included a delay in time to obtain equipment, "The heavy machinery we needed to clear the trails and roads to the farm were not available for many months after the hurricane," and "damaged equipment such as tree-cutting saws, water cisterns, and the water well motors that draw water for their animals."

Thirty-one percent of participants mentioned facing challenges with electricity and fuel shortages, while 23 percent mentioned access and transportation. In reporting challenges with electricity and fuel shortages, some responses indicated a lack of preparation led to the reliance on electric generators. One respondent stated, "Farmers do not prepare ahead of time, so they do not have the vital fuel reserves that are necessary for cattle ranchers. Since the islands' electrical system is fragile, they depend on electric generators."

One respondent indicated concern over providing aid to all areas due to transportation problems, stating, "The biggest challenge is how to manage the recovery aids. Most of the farmers are from very

Table 4. Main challenges faced by land managers

Coded challenges	# of times mentioned	Percentage of respondents who mentioned this as a challenge
Farm management	**147**	**83**
Farm supplies unavailable, ie, seeds, fertilizers, and feed	29	16
Equipment and machinery unavailable and losses	24	14
Infrastructure damage and repair	22	12
Animal care, losses, and dead animals disposal	16	9
Labor unavailable	15	8
Materials for repairs unavailable	10	6
Debris removal and clean up	10	6
Crop losses and damaged crops	6	3
Salvaging and handling down or damaged timber	5	3
Hurricane plan unavailable	4	2
Other	6	3
Electricity and fuel shortages	**55**	**31**
Access and transportation	**40**	**23**
Financial	**39**	**22**
Environmental/ecological	**39**	**22**
Potable water	27	15
Flooding and excess rain	8	5
Landslides and erosion	4	2
Government assistance and aid	**37**	**20**
Communication	**31**	**18**
Markets	**14**	**8**
Personal effects on family and friends	**10**	**6**
Information needs	**7**	**4**

Bold font indicates parent codes, and normal font indicates subcodes (total number of respondents, n = 177).

rural areas where the access to roads are drastically affected after a hurricane." Furthermore, 22 percent of participants mentioned concern over financial issues. Other challenges include those related to environmental and ecological problems—eg, potable water and flooding, mentioned by 22 percent of total respondents—government assistance and aid (20 percent), communication (18 percent), markets (8 percent), personal impacts on family and friends (6 percent), and information needs (4 percent) (Table 4). Of the communication issues, one respondent said, "The main problems were the [lack of] telephone communication and road access."

Frustration over government assistance and aid and political impacts were also evident in some of the responses. One respondent stated, "[A major issue is the] high level of bureaucracy and the very slow payment of subsidies and incentives from regulatory agencies. [Another component of this issue is the] high politicization of the state [government]."

Main challenges faced by advisors assisting farmers and ranchers during hurricane recovery

We subsequently analyzed the second open-ended question, "What is the biggest challenge you face in assisting land managers/landowners during hurricane recovery?" Advisors frequently mentioned multiple challenges (Table 5). Forty-three percent of the respondents indicated difficulty reaching farmers, which included inability to access farms, impassable roads, and landslides (mentioned by 36 percent of total respondents), transportation issues and lack of 4 × 4 vehicles (8 percent), and inability to reach farmers in a timely manner (4 percent).

Open-ended responses indicated that the inability to access farms and communicate with farmers were major challenges following hurricanes. Many respondents indicated transportation due to lack of a 4 × 4 vehicle, landslides, runoff, and storm debris made it very hard to reach farmers. One respondent stated, "The biggest challenge is reaching the farms. My car is not a 4 × 4 and in cases where there are fallen trees or poles, it is impossible for me to access the farms to collect data on damages and to offer recovery recommendations."

Twenty-nine percent mentioned challenges related to working for government agencies. Specifically, respondents mentioned lack of planning and coordination or lack of leadership (mentioned by 14 percent of total respondents), lack of educational materials/information and insufficient training (10 percent), and insufficient financial resources (7 percent) among other government challenges.

Government agency challenges were often discussed as to leading to additional challenges. One respondent stated, "[For government agencies, the main challenge is] the lack of agency preparation and organization. There is no real plan to follow, [forcing us] to work blindly. We are not given information or training on the steps to follow." Several others discussed government agency challenges as a "lack of tools and applicable practices" and a "lack of financial resources required for immediate help."

Communication obstacles, eg, internet and phone lines being down, were shared by several advisors (29 percent). Difficulties with financial assistance for recovery were also shared by several respondents (17 percent), including slow, unavailable, or inadequate aid (10 percent), bureaucratic red tape and excessive paperwork (5 percent), and lack of information about aid (4 percent). Other challenges frequently mentioned related to employees' personal needs (16 percent), farmer challenges (13 percent), and utilities (10 percent) (Table 5).

Several of the personal challenges mentioned were the same that were encountered by farmers and ranchers. Personal challenges included "insufficient supply of water and gas for your own family before going out to help [farmers] and quickly running of our stored supply." One respondent stated, "[One of the biggest challenges for me was that] I was in the same situations as [the farmers I was meant to help]: no food, no water, no gasoline, and [damages to] my house." In assisting with farmers and ranchers, advisors also indicated challenges with assisting with farmer personal challenges and emotional support. One respondent stated, "One significant challenge was the lack of preparedness to deal with the farmers' emotions and reactions after the disaster."

Table 5. Advisors' main challenges assisting landowners (total respondents, n = 163)		
Coded challenges	**# of times mentioned**	**Percentage of respondents who mentioned this as a challenge**
Reaching farmers	**78**	**43**
Unable to access farms/impassable roads/landslides	58	36
Challenges with transportation or lack of 4 × 4 vehicles	13	8
Unable to reach farms in a timely manner	7	4
Government agency challenges	**68**	**29**
Lack of planning and coordination or lack of leadership	23	14
Lack of educational materials/information and insufficient training	16	10
Insufficient financial resources	12	7
Insufficient resources (materials, equipment, seeds, and machinery)	8	5
Insufficient personnel	6	4
Inadequate recovery practices/programs	3	2
Communication challenges/internet and phone lines down	**47**	**29**
Financial assistance for recovery	**31**	**17**
Aid slow/unavailable/inadequate	16	10
Bureaucratic red tape and excessive paperwork	8	5
Lack of information about aid	7	4
Personal employee challenges	**26**	**16**
Provision of emotional or motivational support or feeling powerless to help	23	14
Must attend to personal and family needs	3	2
Farmer challenges	**26**	**13**
Insufficient financial resources	11	7
Land tenure or farm record issues	7	4
Insufficient resources (materials, equipment, seeds, and machinery)	5	3
Lack of planning	3	2
Utilities	**24**	**10**
Fuel shortages	9	6
Lack of potable water or utilities in general	8	5
Power outages and shortages	7	4
Bold font indicates parent codes, and normal font indicates subcodes.		

Preparedness and response

The relative importance and perceived prevalence of hurricane preparedness and recovery strategies among land managers (farmers and ranchers) in the Caribbean. A list of 13 strategies for hurricane preparedness and recovery was given to advisors to gather their perspectives on how important and prevalent these strategies are in agricultural lands. Responses are on a 4-point Likert-type scale (1 = not important; 2 = somewhat important; 3 = important; 4 = very important); mean response (μ) and standard deviation (σ) are reported in parenthesis. Regarding importance, the top strategies for short-term preparedness are *stock up on potable water* (μ = 3.80;

σ = 0.51), *stock up on fuel for generators* (μ = 3.79; σ = 0.46), *stock up on feed* (μ = 3.74; σ = 0.58), *stock up on emergency cash* (μ = 3.73; σ = 0.51), and *reinforce the roofs of structures* (farmsteads, dairies, and enclosures) (μ = 3.72; σ = 0.54). Three of the most important practices were also among the most prevalent practices observed by the advisors in the agricultural lands they serve: *stock up on potable water* (μ = 3.47; σ = 1.15), *stock up on fuel for generators* (μ = 3.42; σ = 1.08), and *inventory livestock* (μ = 3.08; σ = 1.23) (Figure 1).

Following Wiener et al.,[12] we identified strategies with a high importance and perceived low prevalence and categorized them as strategies with an importance-prevalence gap. Specifically, these included strategies with a median importance of *very important* and a median prevalence of *about 50* percent or lower, as well as strategies with a median importance of *important* and a median prevalence of *less than 50* percent or lower. Except for *stock up on potable water* and *stock up on fuel for generators* (median values indicating *very important* and *more than 50* percent prevalence), all the short-term strategies listed had an importance-prevalence gap (Figure 1).

From the list of 16 hurricane-related strategies for long-term preparedness, the following ranked as the top-five in terms of their perceived importance: *create a hurricane preparedness plan* (μ = 3.75; σ = 0.53), *invest in erosion control* (μ = 3.67; σ = 0.59), *establish a water storage system resistant to hurricane winds* (μ = 3.67; σ = 0.61), *create and secure a seed bank* (μ = 3.66; σ = 0.64), and *invest in generators* (μ = 3.59; σ = 0.68). The long-term preparedness strategy ranked as most prevalent is *invest in generators*, which is generally perceived to be applied by *about 50 percent* of land managers. All the remaining strategies listed are considered *important* or *very important*, though applied by *less than 50 percent* of the land managers. Therefore, all the long-term preparedness strategies demonstrated an importance-prevalence gap (Figure 2).

From the list of nine hurricane-related strategies for recovery, the following ranked as the top-three in terms of their perceived importance: *apply for disaster assistance* (μ = 3.82; σ = 0.49), *make crop insurance claims* (μ = 3.79; σ = 0.46), and *inventory livestock* (μ = 3.77; σ = 0.54). These strategies also ranked as the top-three in terms of prevalence. *Examine livestock for infectious diseases, spraying livestock with insect*

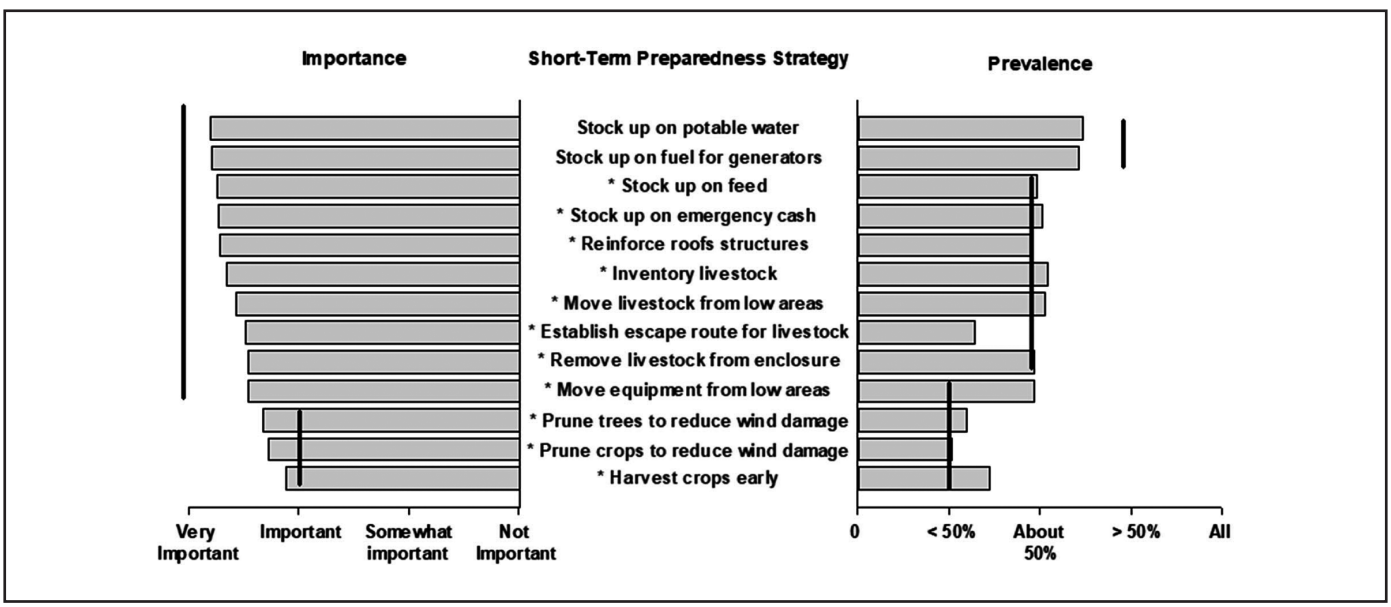

Figure 1. Mean importance and mean perceived prevalence of short-term hurricane preparedness strategies (bars). Vertical lines represent median importance and median prevalence values. Asterisks indicate strategies with an importance-prevalence gap.

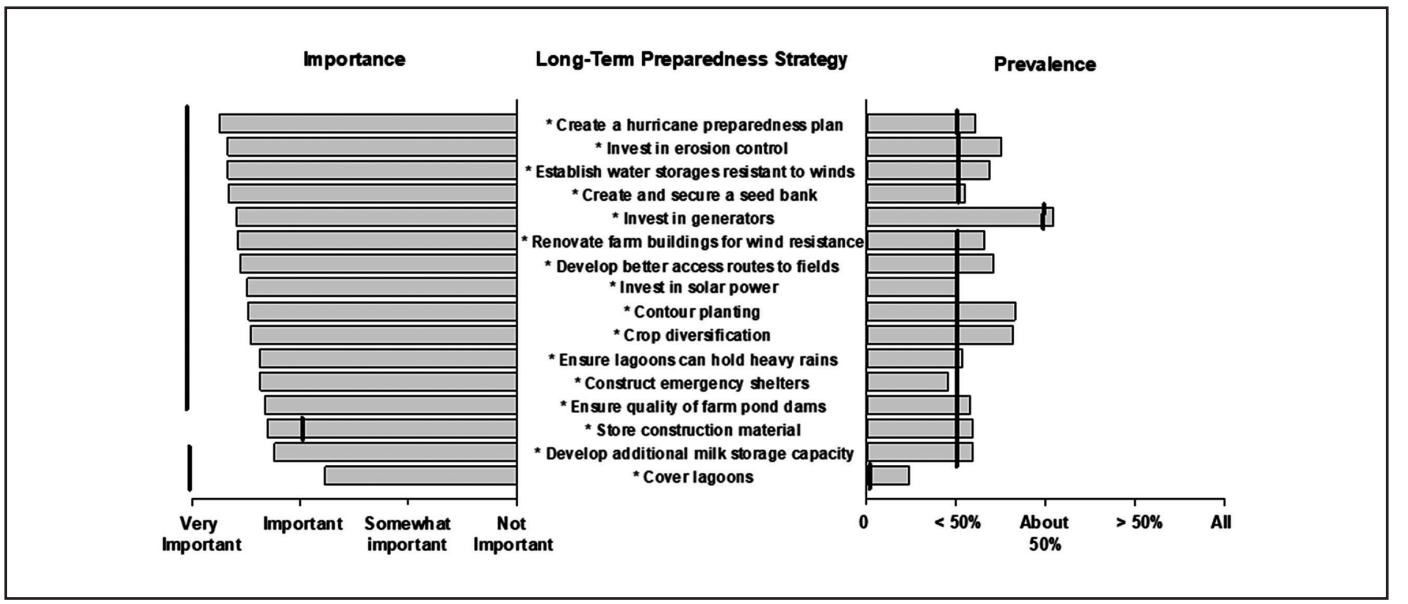

Figure 2. Mean importance and mean perceived prevalence of long-term hurricane preparedness strategies (bars). Vertical lines represent median importance and median prevalence values. Asterisks indicate strategies with an importance-prevalence gap.

repellent, hiring temporary labor, using alternative chemical application techniques, and testing flooded crops for contaminants are considered *important or very important* recovery strategies. However, advisors perceive that these are applied by *less than 50 percent* or *none* of the land managers they serve and as such demonstrated an importance-prevalence gap (Figure 3).

What is needed—advisors

Finally, we analyzed additional resources or information needed by advisors to better assist land managers/owners with hurricane preparation (short and long term) and recovery (Table 6). Qualitative responses revealed a substantial need for professional development resources to better assist in hurricane preparedness and recovery. Approximately 65 percent of the respondents indicated the need for more training and workshops on hurricanes and related topics for the three stages: short-term preparedness (mentioned by 33 percent of total respondents), long-term preparedness (35 percent), and recovery (33 percent).

Several respondents were specific regarding the training content that was needed including "first aid and rescue," "recommended steps to follow during recovery that do not rely on subsidies" and "guidelines on how we can effectively educate farmers." Others were more specific regarding overall training needs. "We need intense workshops on how to preserve water, air and land resources. It is not only important to give the farmers incentives, but also to make them aware of the importance of preserving and caring for the resources." Another response indicated a need for mental health training. "It might be helpful to have psychology workshops to equip us to better attend to farmers during the first visits [after the disaster]." Respondents also suggested methods and logistics of training. One respondent stated, "[We need a] series of videos and lectures on how to prepare for these events. The duration should be no more than 30 minutes and it should be aimed at farmers. I suggest content could be composed of information that is 25 percent [focused on actions to take] before the event, 25 percent during the event, and 50 percent on the recovery process."

Forty-four percent of the respondents indicated the need for additional educational resources and information, principally information on preparedness and recovery practices and fact sheets, reports, guides, or manuals to deliver to farmers. The respondents' request for additional educational resources

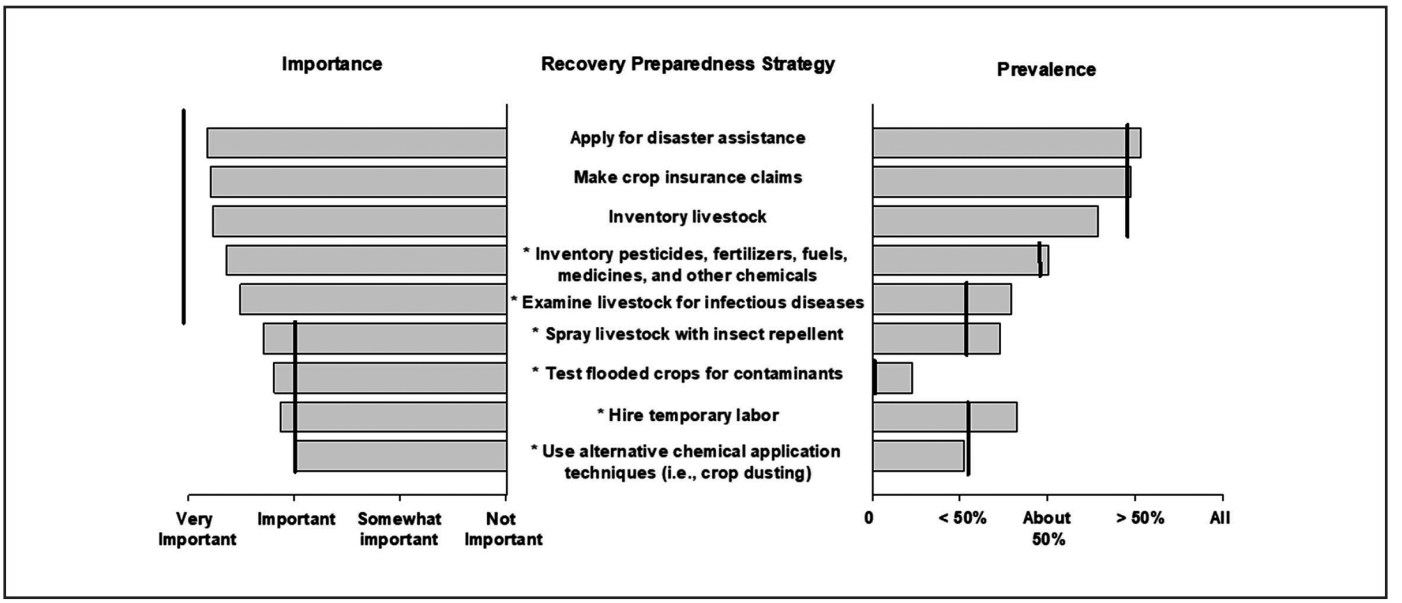

Figure 3. Mean importance and mean perceived prevalence of hurricane recovery strategies (bars). Vertical lines represent median importance and median prevalence values. Asterisks indicate strategies with an importance-prevalence gap.

and information was relatively higher for long-term preparedness (35 percent).

In addition to training and workshop, open-ended responses included a need for information, financial resources, and government coordination. One respondent stated, "up to date on what the agency's plan is, what services and support we can [and can't] provide, and how we can best serve the agency in order to benefit the farmers." Others stated a need for "assistance to fill out the high amount of disaster assistance application paperwork that is required to aid landowners." One respondent stated, "[We need better] coordination in the provision of assistance and services from government agencies. [We need them to prioritize the agricultural sector.] For example, [we need assistance with] animal burial and road cleaning. [It would also be helpful to] inventory the crops before and after the hurricane to determine where the real needs are in terms of opening imports."

Other information requests include information on aid, crop insurance, and programs (24 percent) and information on various management issues (19 percent), particularly during the recovery stage (20 percent). Additionally, multiple advisors (18 percent) called for suitable machinery and transportation means such as 4 × 4 vehicles to reach farms after hurricane events and machinery for debris removal, along with readily available gas and diesel to supply government vehicles. Some respondents (14 percent) urged for more financial resources and improved agencies coordination during emergencies, among other needs (Table 6).

DISCUSSION

Effects

This study examined the effects of hurricanes on US Caribbean agriculture as perceived by agricultural advisors using survey data from over 200 participants across eight institutions. The most prominent effects on the agricultural sector highlighted by advisors in our study—power outages, communication issues, and impassable or closed roads—are consistent with challenges identified in hurricane effects evaluations in both territories.[35,36]

As noted in the introduction, hurricanes Irma and María resulted in the collapse of 80 percent of the power lines and a blackout that left all 3.4 million residents in Puerto Rico without electricity for several weeks. In some areas, the blackout lasted more than 1 year, with only 65 percent of the island's electricity

Table 6. Additional resources or information needed by advisors to better assist land managers/owners with hurricane preparation (short and long term) and recovery (total respondents, n = 97; total number of respondents who commented on short term (n = 79), recovery (n = 49), and long term (n = 60))								
Coded needs	**# of times mentioned**	**Percentage of respondents who mentioned this as a need**	**# of times mentioned under ST needs**	**Percentage of respondents who mentioned under ST needs**	**# of times mentioned under REC needs**	**Percentage of respondents who mentioned under REC needs**	**Percentage of respondents mentioned under LT needs**	**Percentage of respondents who mentioned under LT needs**
Trainings and workshops on hurricanes and related topics	**63**	**65**	**26**	**33**	**17**	**35**	**21**	**35**
Educational resources and information needs	**56**	**44**	**21**	**19**	**7**	**14**	**28**	**35**
Information on preparedness/recovery practices	20	21	6	8	2	4	12	20
Factsheets/reports/guides/manuals to deliver to farmers	17	18	6	8	3	6	8	13
Educational resources general	10	10	6	8	1	2	3	5
Other education recommendations	6	6	2	3	1	2	3	5
Technical resources for outreach	3	3	1	1	0	0	2	3
Information on aid, crop insurance, and other programs	**24**	**25**	**10**	**13**	**10**	**20**	**4**	**7**
Information on various management issues	**19**	**20**	**7**	**9**	**6**	**12**	**6**	**10**
Machinery/transportation	**18**	**18**	**7**	**9**	**9**	**16**	**3**	**5**
4 × 4 vehicles applied	8	8	2	3	5	10	2	3
Heavy equipment	8	8	4	5	3	6	1	2
Gas/diesel availability	2	2	1	1	1	2	0	0
Financial resources	**15**	**14**	**3**	**4**	**2**	**4**	**10**	**15**
Financial resources general	6	6	1	1	2	4	3	5

Table 6. Additional resources or information needed by advisors to better assist land managers/owners with hurricane preparation (short and long term) and recovery (total respondents, n = 97; total number of respondents who commented on short term (n = 79), recovery (n = 49), and long term (n = 60)) (continued)

Coded needs	# of times mentioned	Percentage of respondents who mentioned this as a need	# of times mentioned under ST needs	Percentage of respondents who mentioned under ST needs	# of times mentioned under REC needs	Percentage of respondents who mentioned under REC needs	Percentage of respondents mentioned under LT needs	Percentage of respondents who mentioned under LT needs
Economic aids or emergency funds general	6	6	2	3	0	0	4	7
Incentives for practices	3	3	0	0	0	0	3	5
Agency coordination	**15**	**14**	**4**	**5**	**7**	**12**	**4**	**7**
Coordinated aid efforts among agencies	7	7	2	3	2	4	3	5
Timely response of disasters programs	4	4	0	0	4	8	0	0
Updated records	4	4	2	3	1	2	1	2
Improved means to communicate with farmers	**11**	**11**	**6**	**8**	**3**	**6**	**3**	**5**
Establish, update, and communicate emergency plans	**9**	**9**	**5**	**6**	**2**	**4**	**2**	**3**
Record keeping and paperwork	**7**	**7**	**4**	**5**	**2**	**4**	**1**	**2**
Farmer training	**7**	**7**	**5**	**6**	**1**	**2**	**2**	**3**
Improved infrastructure	**6**	**6**	**1**	**1**	**1**	**2**	**4**	**7**
Other	**8**	**8**	**4**	**5**	**1**	**2**	**3**	**5**

Bold font indicates parent codes, and normal font indicates subcodes.

restored by 15 months after the hurricane.[36] In our study, 71 percent of the participants considered power outages as having devastating effects on farms and ranches. Although many small farmers do not necessarily rely on electricity for production, electricity is generally used in a variety of essential tasks such as the daily management of farm operations, irrigation systems, hydroponics, and aquaculture. Electricity is also essential for communication devices and computer systems involved in everyday business management. During power shortages, farmers commonly relied on generators to continue operations; however, fuel was also scarce after the hurricane. A total of 55 (31 percent) advisors considered both power and

fuel shortages to be an obstacle for farm and ranch recovery (Table 4). Only 4 percent of the advisors mentioned that power shortages were an impediment for providing service during the hurricane recovery. Yet, power shortages posed an internal challenge for communication and coordination among agencies given their dependence on telephones, the internet, computer equipment, and the failure of communication towers connected to the power grid.[37]

Limited telecommunication slowed the recovery process in the agricultural sector as agencies could not effectively provide information on aid availability and application processes, which are usually accessed online. Farmers were asked to make in-person visits to government offices to acquire information on available assistance and aid programs, despite transportation issues.[37] From the advisors' perspectives, lacking phone communication to connect with farmers to check on their wellbeing and the status of their farm was a significant setback. More than half of the advisors in our survey described that communication issues such as downed phone lines or lack of internet access had devastating impacts on agricultural lands and operations. Likewise, approximately one-third of surveyed advisors consider that problems with communication, internet, and downed phone lines impeded their ability to assist farmers and ranchers during the agricultural recovery process.

Agriculture in rural mountains away from main roads likely suffered the most significant effects associated with isolation due to a higher density of landslides.[38] Notably, the lack of road access significantly hindered the livestock sector. For several weeks during the aftermath, distribution trucks could not access livestock farms to retrieve milk in a timely manner. As cows continued to be milked, millions of gallons of milk had to be discarded in many farms around the island. Farms frequently relied on a generator to operate, but the long-term dependency on generators to run refrigeration tanks for milk storage was not sustainable, especially with fuel shortages.[39] Impassable roads hindered recovery in the agricultural sector in general. Advisors mentioned accessibility, along with communication and transportation issues as the principal challenge to assist farmers and ranchers during the recovery period. The absence of enough 4 × 4 vehicles was mentioned as an important limitation to reach farmers in times of recovery. Moreover, in our survey, more than 50 percent of the advisors consider that fallen trees had devastating effects on agricultural lands across Puerto Rico and USVI, eg, downed fences and blocked access. Our study shows the urgency of incorporating a mechanism to respond effectively to the removal of fallen trees on farms and along transit routes to expedite the recovery process in agricultural areas.

Preparedness and recovery

In investigating hurricane preparedness and recovery strategies applied by farmers and ranchers, our survey results suggested limited implementation of long-term practices for hurricane resilience, though data indicated farmers implement some important short-term preparedness and recovery strategies. From the long-term strategies evaluated, all showed an importance-prevalence gap, meaning that even though these strategies are considered important by advisors, the number of farmers or ranchers incorporating them is limited.

Although many of the advisors indicated a high level of confidence in their ability to assist land managers on general topics related to hurricanes, the results highlight a notable desire for more training, workshops, and educational information on hurricane preparedness and recovery. A greater need was expressed for educational resources for long-term preparedness strategies. Agencies could modify previous resources to reflect the strategies needed to cope with the expected effects of more frequent and more intense hurricanes foreseen for the region. As most of the respondents acknowledge relying on training, workshops, and webinars, and resources from Cooperative Extension for hurricane information, these can be considered reliable venues to support advisors' educational needs.

Advisors in this study considered creating a hurricane preparedness plan to be the most important long-term strategy of those presented in the survey, but they perceived that fewer than 50 percent of farmers and ranchers in the regions have developed or adopted

one. Advisors also indicated that the lack of planning and coordination in government agencies created challenges when assisting farmers and ranchers during hurricane recovery. As there is an expected increase in the frequency of intense hurricanes, hurricane preparedness that includes practices with long-term outcomes for resiliency would be beneficial and should become a priority for all agrarian sectors in the US Caribbean. Anticipatory national-level planning that incorporates approaches for tackling the most devastating effects on agriculture would likely reduce vulnerability and cost while decreasing recovery times. Also, it is important to generate research on the effectiveness of agricultural practices recommended for long-term hurricane resilience applied in the Caribbean, as many of the current standards come from experiences in the US mainland.[12]

Government agencies, through their advisors, could more consistently connect with leaders from the different agricultural sectors, eg, poultry, banana, and milk, in order to design tailored management plans that incorporate lessons learned from the 2017 hurricanes. In addition to supporting sector-specific plans, government agencies would likely increase effectiveness by considering coordination to help not only in the immediate response to hurricanes but also long-term preparation for extreme climate events. For instance, government agencies can coordinate information campaigns on program availability, develop and promote incentives that support long-term preparedness strategies, and streamline application processes to programs and aid.

Creating and securing a long-term seed bank was another large prevalence-important gap. Respondents also indicated that lack of seeds for crop recovery and for tree planting was a significant recovery challenge. The coffee and cocoa sectors, in particular, were affected by the lack of seeds to restore plantations.[40] After the hurricanes, the coffee sector recommended importing seeds from outside of Puerto Rico to increase available seeds from 2 to 7 million seeds, which could cut recovery times from 10 years to 2-3 years.[41] Supported by Agricultural Extension Services, efforts are now underway to provide training and workshops in nursery management, and establishing coffee nurseries and seed banks.[40]

Other long-term practices that ranked high in their importance-prevalent gap are practices that can be adopted with the technical or financial support from government agencies, ie, NRCS, including erosion control, contour planning, and crop diversification. Strategies that support better infrastructure, such as water storage resistant to winds, can also be adopted with cost-share support from NRCS. However, lack of information about conservation programs, conflicting programs, and distrust in government, among other variables, may hinder participation.[42] Agencies should also evaluate the institutional barriers and policy inconsistencies that limit farmer and rancher participation in agricultural conservation programs that can increase agricultural resilience to climate events.[42]

The most prevalent long-term practice among ranchers and farmers was investing in generators. Although around 81 percent of the advisors indicated that fuel shortage had a devastating or high impact on the agricultural sector, stocking up on fuel for generators is a short-term preparedness strategy that is prevalent in the region. Costs and access to fuel constituted a significant challenge in the aftermath of the hurricanes. Both in Puerto Rico and USVI, the government is moving to supporting alternative ways of power operations in the agricultural sector, but many of these are costly. Suggested solutions include highly distributed alternative power sources, local fuel distribution centers, plans aimed specifically for agricultural customers, and renewable on farm energy generation such as wind, solar, and biofuels.

Applying for insurance and aid were recovery strategies prevalent among farmers and ranchers. In Puerto Rico, the FIC is the Approved Insurance Provider (AIP) that sells and services federal crop insurance policies through a public–private partnership with USDA Risk Management Agency. Nevertheless, coverage is limited to select crops and is not common on smaller farms, so many farmers were unable to access insurance benefits. Moreover, there is no AIP for federal crop insurance in USVI. Before the hurricanes, cocoa farming in Puerto Rico was increasing, but the sector lost most income due to hurricane damage and a lack of available insurance.

Without income and very limited assistance for recovery, cocoa producers have struggled to resume their cocoa farming operations in Puerto Rico. With little to no income, many employers were unable to pay wage workers, and many farm employees have been unable to resume work since the hurricanes.[41] Financial assistance for recovery was also mentioned by 17 percent of the advisors as a challenge for recovery in the aftermath of the hurricanes, largely associated with the fact that so many farmers were in search of limited aid and with the challenges in providing the requisite documentation and records.

Farm-level recovery was also greatly hindered by the unavailability of supplies (seeds, fertilizer, and feed), equipment, and machinery. These findings echo previous post-hurricane observations in farms in Puerto Rico. Farmers expressed that the most significant obstacles toward recovering from hurricane María were related to farm-level recovery, followed by government-related obstacles—eg, lack of planning and coordination, or lack of leadership—and lack of utilities.[43] In the coffee region of Puerto Rico, farm-level management to control undesirable species, eg, vine cover and insects, was the most critical issue for hurricane recovery.[11] Farmers with resources to eliminate vines, hire labor, or use herbicide proved to be more resilient than farmers without economic resources or community and support.[11]

Considering the challenges faced during the recovery period, advisors expressed not having the skills to help farmers cope with the psychological effects resulting from the hurricane devastation. In all, 16 percent of those who answered this question indicated that they did not feel skilled enough to provide emotional or motivational support to farmers and ranchers, and that they felt powerless to help them. Also, their own personal and family needs were a significant challenge in the process of recovering from the hurricane devastation. Emotional devastation or stress was prevalent among farmers in general.[40] The advisors, often the first to contact farmers, are faced with providing emotional support in times of crisis. The psychological effects of natural disasters such as hurricanes are known from experiences resulting from hurricanes Mitch and Katrina.[44,45] Previous research also shows that the resulting effects of such disasters on mental health are associated with long-term problems in health, recovery, and the economy.[46] To our knowledge, no post-hurricane assessments of first-responders' psychological health have been conducted in Puerto Rico and USVI. Furthermore, the necessary training needed to cope with the post-hurricane psychological effects has yet to be evaluated. Training designed to deal with emotional stress during hurricane response could be incorporated by agricultural agencies that provide direct service to farmers.

Limitations

Some limitations and challenges of this study should be noted. First, some inconsistencies in responses may have resulted from distributing both an online and paper version of the survey. However, due to the instability following these hurricanes, using only online or only paper surveys was not feasible. Second, we requested that the survey be sent to staff who assist land managers involved with hurricane preparedness and recovery. Given that the research team did not directly distribute the survey, we do not know precisely how many people received the survey, so we could not calculate a response rate. The inability to calculate a response rate makes it difficult to determine if the survey was representative. Still, we believe the sample size, ample participation across the various organizations, and the targeted outreach produced valuable results. Distribution through leadership was the most appropriate mechanism available to us. Third, while agricultural advisors provide valuable insight into land manager actions, the methodology is imperfect in that respondents may not reach every land manager, and their perceptions may only reflect a portion of the challenges faced after the disaster. However, we believe this study creates a baseline of information around which to develop future studies and provides a rapid assessment after major hurricanes.

CONCLUSIONS

The cost of extreme climate events is increasing dramatically, both in terms of the economic costs of individual events, and in terms of the economic, social,

and ecological costs of compounding events, occurring simultaneously or in rapid succession. Because of this, the cycle of disaster preparedness, response, and recovery is increasingly complex. The strain of larger and more frequent events has revealed gaps in the way agencies collaborate to help citizens prepare for and recover from disasters. Recovery resources do not reach all in equal measure. This was explicitly true in the US Caribbean in recent years, as the region suffered severe drought in 2014 to 2016, intense hurricanes in 2017, and repeated earthquakes in 2020. The short time frame between disasters increases the vulnerability of agriculture and forestry operations to economic and functional losses. The imperative to learn from experience and improve communication and adoption of best practices is paramount to reducing the risk of extreme climate events.

More specifically, climate projections indicate that the Caribbean will experience more intense hurricanes, increasing challenges to the islands' agricultural and economic development, and food security. Agricultural advisors in this study perceived the effects on farmlands in Puerto Rico and USVI from the major hurricanes of 2017 to be significant and devastating. Most significantly, the implementation of highly important practices for preparedness before the arrival of the hurricanes was generally perceived as limited, except for the practices of stock piling water or fuel. Despite stocking these resources, shortages presented substantial challenges due to the length of the recovery period. Furthermore, the recovery stage was perceived to be impeded by a lack of materials and equipment, transportation and communication issues, lack of planning, and ineffective agency coordination. Finally, the incorporation of long-term preparedness practices important to face future hurricanes was perceived to be largely absent.

There is a pressing need to improve hurricane preparedness, response, and recovery to minimize effects on farmlands and to ensure the timely recovery of the agricultural sector in the Caribbean after hurricanes. Much of the improvements in these areas are driven by a diverse set of agencies. As this study indicates, planning, response, and recovery are impeded by a lack of agency coordination. Improvements in hurricane planning can be accomplished with an increased level of organization and coordination among agencies. Integrated efforts could include a revision of the aid application processes, as well as the development of sector-specific emergency and recovery guides. Every hurricane's recovery period illuminates opportunities to improve the response efforts and to better attend to the needs of the agricultural sector for future hurricanes. This study supports the need for more coordinated efforts in the integration and collection of data among emergency management and agricultural agencies to help expedite hurricane response and mitigation. Our study also reveals a gap in training and educational resources on hurricane preparedness among agricultural advisors, particularly concerning long-term strategies. We emphasize the need for the development of training for managing emotional distress of advisors, given that while they support affected populations, they also suffer the effects of hurricanes themselves. With the certainty that hurricanes will continue to affect the Caribbean region, it is imperative to take proactive measures from the farm level to the agency level to (1) improve efficiency and prevalence of preparedness and recovery efforts, (2) increase the resilience of farm systems, road systems, and energy systems, and (3) support the psychological needs of those on the front lines and directly affected by hurricane events.

ACKNOWLEDGMENTS

We are grateful for the generous participation of agency employees who helped distribute and participated in the survey. Special thanks to those who pretested the survey: S. Brogan, L. Johnson, S. Prieto-Pulido, E. Mas, R. Rodríguez, M. Argüelles, and J. Rosario. Thanks to S. Aucoin, K. Jacobs, L. Villanueva, E. Holupchinski, B. Maldonado, and A. Lugo for insightful comments to previous versions of the manuscript. T. Díaz and C. de Jesús assisted with survey translation. M. Andrade assisted with data entry. This manuscript benefited greatly from the input of two anonymous reviewers. We acknowledge the personnel of the Extension Service of the University of Puerto Rico at Mayagüez, who helped in different stages of the project. All research at the USDA Forest Service International Institute of Tropical Forestry is done in collaboration with the University of Puerto Rico.

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